Recent Signature Modelling Studies To Predict The Impact Of Hull Openings And ICCP System Anode Failure

Cristina Peratta, Robert A Adey, John M W Baynham, Guy Bishop

CM BEASY Ltd, Ashurst Lodge, Southampton, Hampshire, SO40 7AA, UK

Abstract

The progressive advance of computational resources and developments in computer modelling in the last few decades has made computer modelling of complex CP systems widely available. A computational modelling approach is one of the most effective tools for the design of corrosion control systems and optimization of ship electric and magnetic signatures. In this study the focus however was on using computer modelling to assess the robustness and sensitivity of the vessel ICCP system to the impact of anode failures, damage, coating degradation, hull opening and appendages etc. Of particular interest was the corrosion related electric and magnetic signatures.

Keywords: ICCP, Cathodic Protection, Signature, CRM, UEP, Sea Chest

Introduction

Computer modelling is now widely used to predict how effective cathodic protection (CP) systems are at protecting marine vessels against corrosion and to understand the associated electric and magnetic fields caused by the cathodic and anodic currents flowing through the seawater to and from the vessel hull. Ships are protected from corrosion by a combination of coatings and cathodic protection systems which impact the anodic and cathodic currents by providing a resistance to current flow in the case of coatings and by actively creating cathodic currents to protect the vessel in the case of CP. CP systems are based on either sacrificial anodes or impressed anodes (ICCP) or some combination of the two types. Impressed anodes are often referred to as “active” systems since they can respond to changes in the protection requirements because they are connected to some form of control system. Typically in computer models ICCP anodes are controlled by specifying either the voltage or the current they output in response to the potential measured at a reference electrode.

Typical input requirements for a computer model are:

- Physical and geometrical properties of the electrolyte and hull wetted surfaces
- Anode sizes and locations
- Reference electrode set points and locations
- Condition of any coatings/paints
- Polarization properties of the materials involved

Typical outputs of the simulation are:

- Anodic and Cathodic Currents
- Protection Potentials

- Electric and Magnetic Signatures

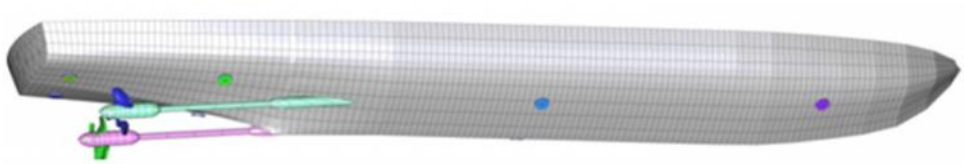

Figure 1 Simulation model of a ship showing the computational mesh used to represent the shape and properties of the vessel

Case Studies

In the paper two examples will be presented. The first is a study to simulate the impact of an anode failure on the performance of the ICCP system and the resulting effect on the vessel's signature. The simulation included the active ICCP control system, redistribution of the currents, the updated potentials on the hull and the new signature. In the second study the impact of current flowing from CP anodes in sea chests and similar structures on the protection of the hull and the signature is predicted. Of particular interest is the modelling of the gratings which are used to protect hull penetrations.

Case Study 1 ICCP/CP System Robustness

In this first study the objective was to simulate the impact of an anode failure on the performance of the ICCP system and the vessel's corrosion related signature. The simulation included the active control of the ICCP control system to achieve the set points at the reference electrodes and the redistribution of the anode currents from the failed anodes through the ICCP electrical circuits

Early modelling approaches for ICCP systems connected to a power supply assumed constant distribution of currents between the anodes. However as modelling tools became more sophisticated it became possible to model the electrical wiring circuits and resistances, characteristics of the power supply (TRU) and the real time performance of the ICCP digital controller. More recent developments have included the simulation of the ICCP anode polarisation for materials such as Mixed Metal Oxide (MMO) and the creation of multiple complex electrical circuits including electrically isolated structures and independent circuits.

Figure 2 shows the model locations of the anodes and reference electrodes (RE) and the electrical connections between the anodes and the TRU indicated. The resistance values between the different anodes and the shaft grounding electrical resistance are also shown.

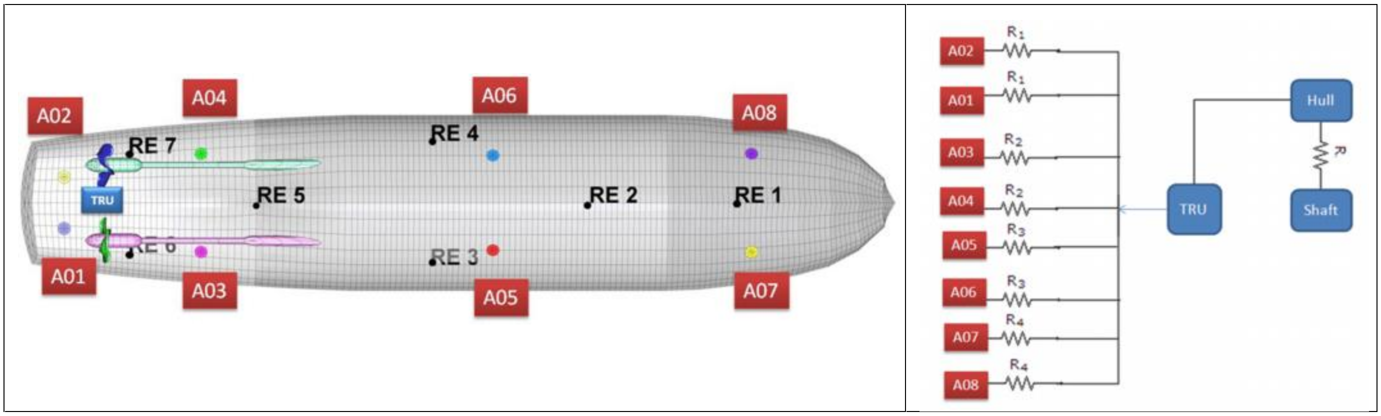

Figure 2 Ship anode and reference electrode locations. The electrical connections are shown assuming the TRU is located in the stern

A series of scenarios was planned as shown in Figure 3 including six different anode failures scenarios assuming perfect shaft grounding, a case where the shaft is isolated and a scenario where there was imperfect shaft grounding represented by a resistance between the shaft and the hull.

CASE STUDY 1			
	DESCRIPTION	ANODE FAILURE	CASE NAME
A Cases Shaft electrically connected	All anodes functioning	-	A0
	Connections broken corresponding to the following anodes	A01	A1
		A03	A2
		A05	A3
		A07	A4
		A01,A02,A03,A04	A5
		A05,A06,A07,A08	A6
Case B Shaft electrically isolated	All anodes functioning	-	B0
Case C Shaft connected with resistance 0.05 Ohms	All anodes functioning	-	C0

Figure 3 Failure scenarios considered in the study

The Set Point for the ICCP system was specified as -930mV vs Ag Ag/Cl and the simulations were performed to achieve a potential of at least -930mV ±0.010mV at the RE's. For the different cases studied the TRU output was adjusted to match the set point at RE 6 as this RE indicated the most positive potential. Figure 4 shows the potentials at each of the reference electrodes for the different anode failure scenarios. In all cases it was shown that the ICCP system was capable of achieving the required protection potentials on the hull.

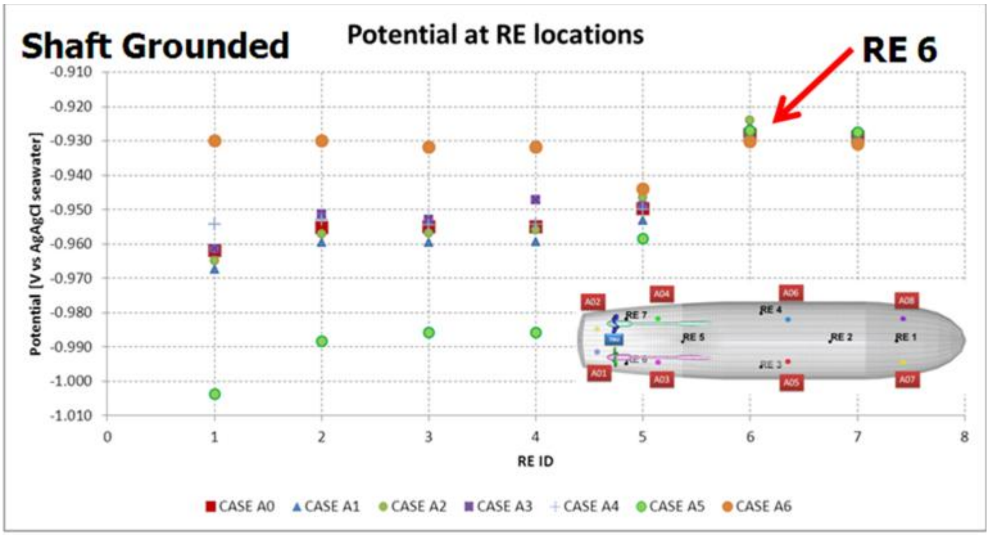

Figure 4 Predicted potentials at the reference electrodes (X axis)

Figure 5 shows the currents delivered by each of the anodes for the different failure scenarios. How the ICCP system redistributes the current can be clearly seen and a similar total anode current was sufficient for all the cases.

	CASE A0	CASE A1	CASE A2	CASE A3	CASE A4	CASE A5	CASE A6
	Total Current delivered per individual anode [Amps]						
ANODE A01	1.51	0.00	1.73	1.69	1.68	0.00	2.67
ANODE A02	1.51	1.80	1.73	1.69	1.68	0.00	2.67
ANODE A03	1.39	1.62	0.00	1.56	1.55	0.00	2.53
ANODE A04	1.39	1.61	1.60	1.56	1.55	0.00	2.53
ANODE A05	1.21	1.40	1.39	0.00	1.37	2.73	0.00
ANODE A06	1.21	1.40	1.39	1.38	1.36	2.73	0.00
ANODE A07	1.15	1.33	1.32	1.31	0.00	2.59	0.00
ANODE A08	1.15	1.33	1.32	1.31	1.31	2.59	0.00
Total TRU output	10.50	10.50	10.50	10.50	10.50	10.65	10.40

Figure 5 Predicted anode currents for different failure scenarios with the shaft grounded

An important design requirement for naval vessels is the strength of the corrosion related electric and magnetic signatures. The total corrosion related magnetic signature is a combination of the magnetic fields generated by the corrosion currents flowing through the sea water and the magnetic fields generated by the corrosion currents flowing through the hull and returning back to the TRU. The model calculates both magnetic fields and computes the total magnetic signature for the different failure scenarios as shown in Figure 6

While failure of individual anodes has little overall impact on the magnetic signature the failure of the anode group near the aft section of the vessel causes a major increase. This is not surprising as the hull is assumed to be in good condition with a 1% breakdown factor so a significant flow of the current is to the NAB propellers.

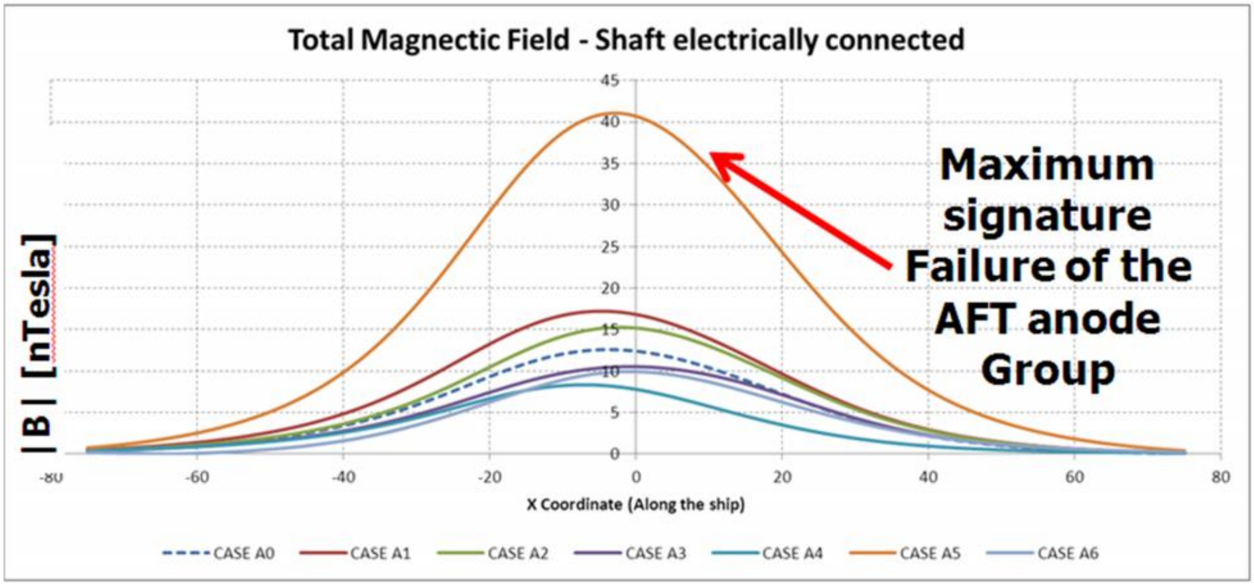

Figure 6 Predicted magnetic signatures for different failure scenarios assuming the shaft was grounded

The results presented so far have assumed that the shaft is perfectly grounded to the hull. In the following study the effect of a failure of the shaft grounding is simulated assuming all the anodes are active.

	CASE A0 Shaft electrically connected	CASE B0 Shaft electrically insulated
	Total Current delivered per individual anode [Amps]	
ANODE A01	1.51	0.43
ANODE A02	1.51	0.43
ANODE A03	1.39	0.43
ANODE A04	1.39	0.43
ANODE A05	1.21	0.40
ANODE A06	1.21	0.40
ANODE A07	1.15	0.39
ANODE A08	1.15	0.39
Total TRU output (RE6 at 0.930±0.010 V)	10.50	3.29

Figure 7 Predicted anode currents assuming all the anodes are active with variation in the shaft grounding

Figure 7 shows the currents delivered by the anodes for different levels of shaft grounding. When the shaft is not grounded the current demand is significantly reduced. With partial shaft grounding the current demand will depend upon the resistance between the shaft and the hull and fall somewhere between the two values. If for example the shaft bearing resistance varies between the two cases shown the current will modulate between the two values predicted as the shafts rotate.

Figure 8 shows the variation in the total magnetic field for the different shaft grounding options assuming all the anodes are active. If the shaft resistance to the hull varies with the rotation of the shaft the magnitude of the ELFE ripple can be determined from these simulations.

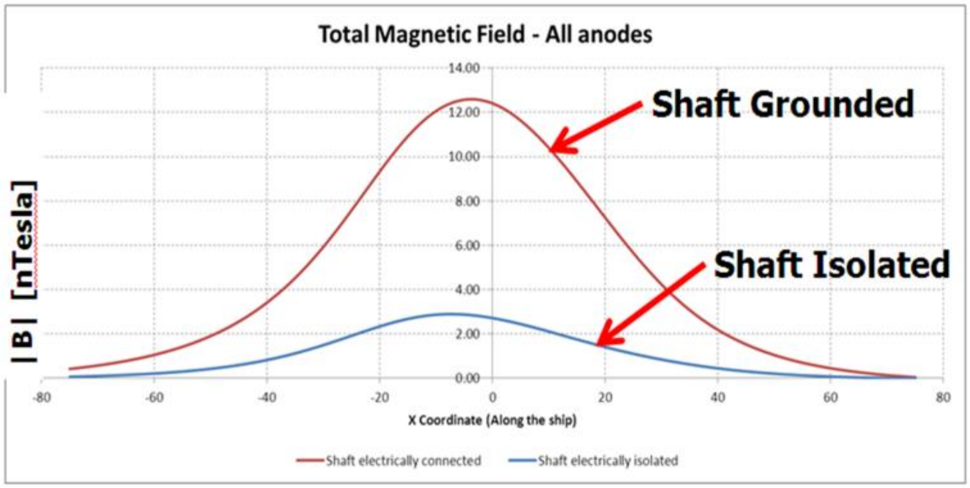

Figure 8 Predicted variation in the total magnetic field for different shaft grounding assumptions

Case Study 2 Sea Chest & Ballast Tanks

In the second study the impact of current flowing from CP anodes in sea chests and sea water ballast tanks on the protection of the hull and the signature is predicted. Of particular interest in the study is the effect of the gratings which are used to protect hull penetrations. In some applications only a very small percentage of the hull requires significant levels of cathodic protection due to the presence of special hull treatments over most of the wetted hull. Consequently the ICCP system requires very precise regulation of both current output and potential control as under these conditions internal spaces begin to have an effect on the ICCP operation and current distribution.

The sizes of hull penetrations vary from just a few cubic metres to ones with significant larger volumes depending on the size of the vessel. Flush fitting steel grills with either round holes or slots prevent large debris from entering the sea-chests during ballast pumping and the size of the grill can significantly impact the current entering or leaking from the internal compartment so a crucial element is the accurate modelling of the grills.

An internal compartment protected by a stainless steel grating is shown in Figure 9. It is protected internally by a single anode. The construction material of the grill itself can also have a significant impact on the current distribution as can be seen in this study.

The simulation process was similar to that described in Case 1 in that the TRU current output was adjusted until the RE achieved the set point. The RE potentials are shown in Figure 10. The addition of the gratings and the internal compartment requires an increase in the current supplied by the TRU to achieve the set point at the reference electrodes as shown in the figure.

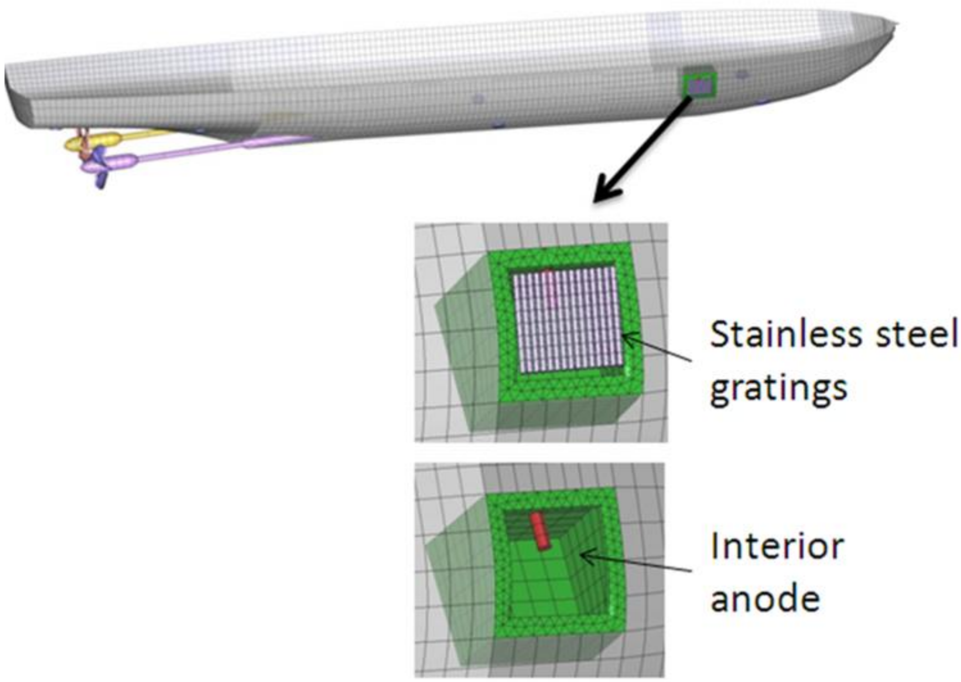

Figure 9 Hull penetration with stainless steel grating and internal anode

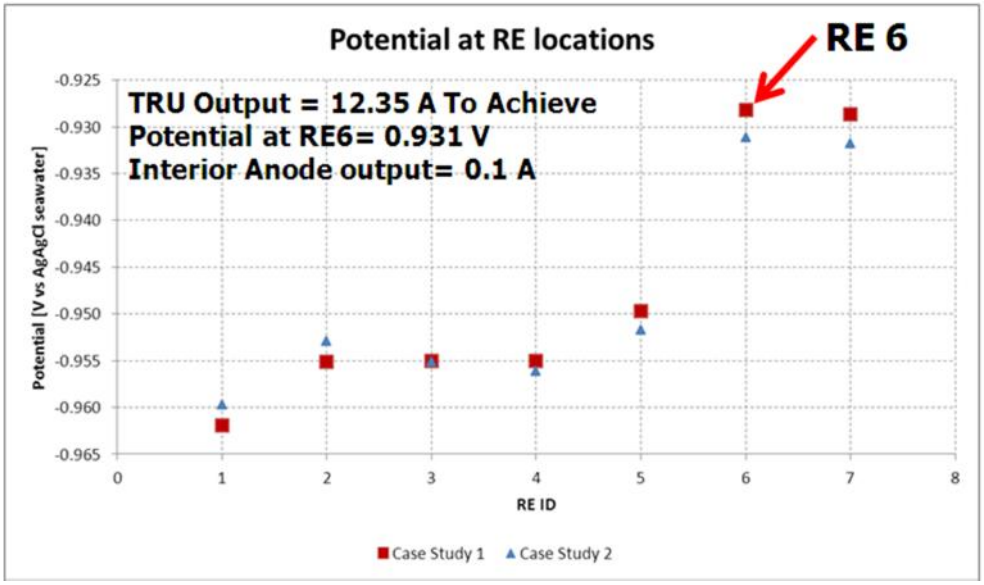

Figure 10 Predicted potentials at re locations with hull penetration with the assumption that the shaft is grounded and all anodes are active

Figure 12 shows a comparison of the currents delivered by the anodes for the Case study 1 (without the hull penetration) and Case study 2 (with the hull penetration) when the shaft is grounded to the hull and all the anodes are functioning. As can be seen the increase in current from the TRU to meet the set point is evenly distributed between the anodes.

Figure 11 and Figure 13 show the predicted potentials on the vessel for the case with the hull penetration and grating and a comparison with the potentials without the prenetration.

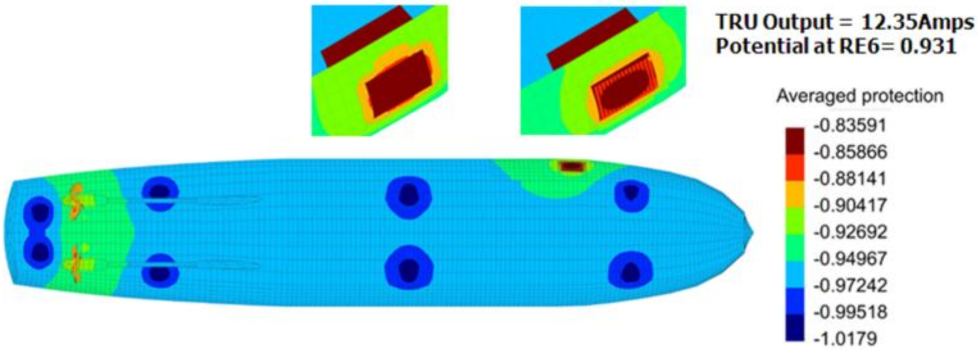

Figure 11 Predicted hull potentials with hull penetration assuming the shaft is grounded

	CASE STUDY 1 A0	CASE STUDY 2 A0
	Total Current per individual anode [Amps]	
ANODE A01	1.51	1.75
ANODE A02	1.51	1.75
ANODE A03	1.39	1.61
ANODE A04	1.39	1.62
ANODE A05	1.21	1.43
ANODE A06	1.21	1.44
ANODE A07	1.15	1.37
ANODE A08	1.15	1.40
Total TRU output (RE5 at 0.930±0.010 V)	10.50	12.35

Figure 12 Predicted anode currents with hull penetration and the shaft grounded

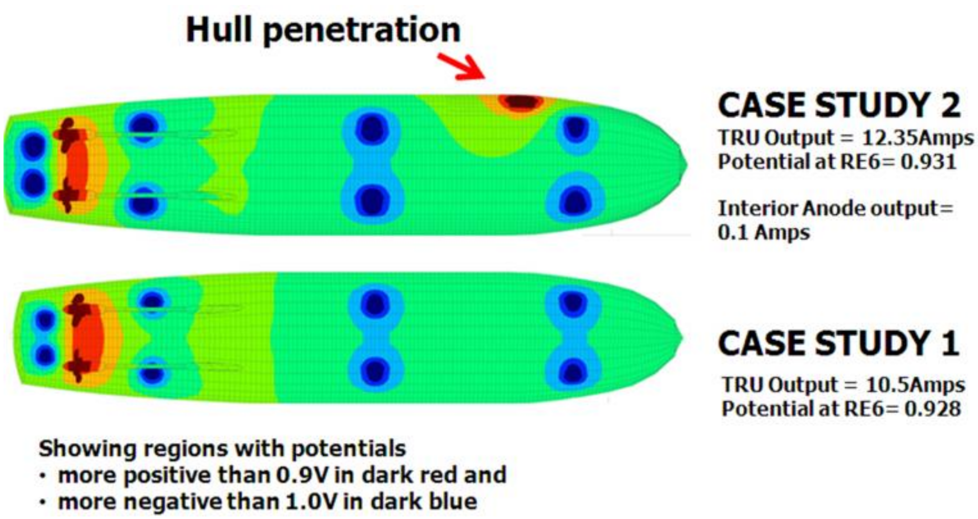

Figure 13 Predicted hull potentials with and without hull penetration assuming the shaft is grounded and all anodes are active

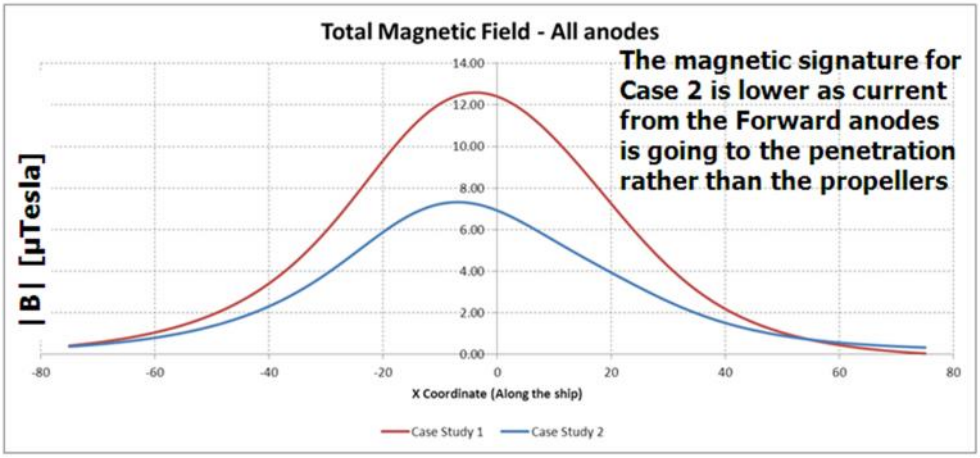

Figure 14 Predicted magnetic signature with and without the hull penetration assuming the shaft is grounded and all anodes are active

Figure 14 shows the magnetic signature for the Case 1 and Case 2 (with the hull penetration and grating). It is interesting to note that the overall signature is reduced because less current is flowing from the forward anodes to the shafts and propellers thus reducing the distance the current flows and hence the dipole effect.

Case Study 1 Shaft grounded	Maximum Combined Magnetic Field magnitude (nTesla)	Maximum Electric Field magnitude (µV/m)
All anodes working	12.6	84.8
Anode A1 failure	17.2	109.8
Anode A3 failure	15.3	101.1
Anode A5 failure	10.5	71.2
Anode A7 failure	8.3	63.2
Anodes 1 to 4 failure	41.1	241.4
Anodes 5 to 8 failure	10.0	47.0
Case Study 1 All anodes working	**Maximum Combined Magnetic Field magnitude (nTesla)**	**Maximum Electric Field magnitude (µV/m)**
Shaft grounded	12.6	84.8
Shaft electrically isolated	3.9	28.2
All anodes working Shaft grounded	**Maximum Combined Magnetic Field magnitude (nTesla)**	**Maximum Electric Field magnitude (µV/m)**
Case study 1	12.6	84.8
Case study 2	7.3	57.6

Figure 15 Electric & Magnetic Field Signature Envelope

Figure 15 show a summary of the electric and magnetic signatures for all the scenarios studied which represent just a few of the possible investigations which could be performed. As can be seen from the two studies comprehensive sets of data can be obtained by using the model to simulate various scenarios. This data can be combined with data on the ferromagnetic field and with data associated with the location of the vessel and its operating environment to provide a complete picture on the vessels signature envelope and the robustness of the protection provided to the vessel.

Conclusions

The focus of this study has been the assessment through the use of computer modelling of the robustness of a ships corrosion control systems. In particular the impact on the protection provided to the vessel and the corrosion related electric and magnetic signatures of anode failures, internal CP systems with Hull opening and other appendages etc.

New developments have been presented demonstrating the ability to predict the complex interactions between the components of a ship ICCP system.

In the first study the impact of various anode failures in the ICCP system was predicted showing the ability of the CP system to maintain protection, demonstrating the ability of the chosen Reference Electrodes to provide control to maintain the protection of the vessel and indicating the likely changes in the ships signature.

In the second study the influence of CP systems in internal compartments (connected through the hull via gratings to the surrounding sea water) was predicted showing the impact on the ability to control the ICCP system, the importance of gratings and other appendages particularly on the location of Reference electrodes, the possible increase in the current required by the ICCP system and shows the impact on the signature. For example the signature changed considerably when the penetration and gratings were included

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